AN EXTENSION TO THE PRO-MPEG COP3 CODES FOR UNEQUAL ERROR PROTECTION OF REAL-TIME VIDEO TRANSMISSION

César Díaz, Julián Cabrera, Fernando Jaureguizar, and Narciso García

ABSTRACT

We propose and evaluate an extension to the Application-Layer FEC (AL-FEC) codes introduced by the Pro-MPEG Forum in its Code of Practice 3 r2 (Pro-MPEG COP3 codes), consisting in allowing the use of a number of matrices of dissimilar size per FEC block. So, unequal protection of the data packets in the video stream is enabled, since dissimilar code rates can be applied to different groups of data packets. This boosts the efficiency of the protection scheme, increasing the video quality of the sequence presented to final users, even if the resulting packet loss rate (PLR) after channel decoding remains the same. Evaluation results show a significantly better performance of the Pro-MPEG COP3 codes when the proposed protection extension is incorporated.

***Index Terms*—** Video streaming, IP networks, real time, distortion, UEP, AL-FEC

1. INTRODUCTION

In scenarios in which multimedia content is streamed through managed IP networks, Application-Layer Forward Error Correction (AL-FEC) mechanisms are commonly used to overcome the unreliability of the communication channel and meet target Quality of Service (QoS) requisites [1] [2].

The selection of the actual AL-FEC code to be included in the system depends on how well its features fit the needs of the specific transmission scenario [3][4]. In this paper, we focus on the well-known AL-FEC codes introduced by the Pro-MPEG Forum in its Code of Practice 3 r2 [5] (Pro-MPEG COP3 codes), as they have very attractive features. Especially their low complexity and their capability to cope with burst errors are very much appreciated in real-time streaming over packet-switch networks. These codes were standardized by the SMPTE in its specification 2022-1 [6] and then included in the DVB-IP Phase 1 Handbook (ETSI TR 102 993) [7]. They have been widely deployed, both alone and jointly with a second code [7][8].

The analysis of the performance of these codes shows that they work very satisfactorily as long as the channel PLR is sufficiently low. However, they become less efficient as network conditions toughen, thus inadequately protecting the video stream, which many times might lead to intolerable levels of degradation of the video presented to final users [3].

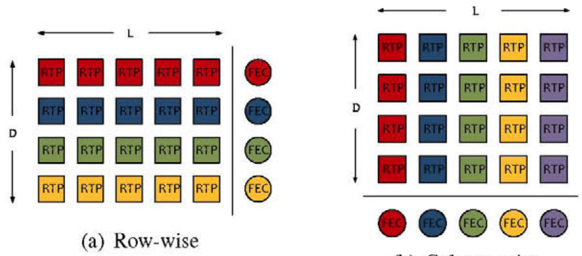
With the purpose of improving the performance of Pro-MPEG COP3 codes at high PLRs, we propose an enhancement consisting in allowing the use of a number of matrices of dissimilar size per FEC block. Thus, unequal code rates can be applied to different groups of packets. The grouping of data packets and the distribution of repair packets among groups are done in regard of the unequal importance of the transmitted video packets in terms of error propagation and observing the imposed overall overhead limitation. This way, we enable simple packet-level Unequal Error Protection (UEP) of the video stream, leading to acceptable levels of video quality, even if the PLR remains high.

The rest of the paper is organized as follows. Section 2 introduces the standard Pro-MPEG COP3 codes scheme. Next, in section 3, the proposed extension of the codes is described. In section 4, we perform an evaluation of the proposal and present results. Finally, in section 5, we include the conclusions of the paper.

2. STANDARD PRO-MPEG COP3 CODES

The standard Pro-MPEG COP3 codes works as follows. First, data packets are arranged in matrices of D rows and L columns. Then, repair packets might be generated both row-wise and column-wise by XORing the corresponding data packets. This is depicted in Fig. 1. The protection packets created row-wise are suited to deal with independent packet losses, whereas the ones built column-wise aim at coping with burst errors. So, the number of data packets per FEC block, k, equals $D \cdot L$, whereas the number of repair packets depends on whether one or both dimensions are utilized.

The configuration of the Pro-MPEG COP3 codes, i.e., the values of the parameters D and L, and whether to obtain repair packets only row-wise, only column-wise, or both ways, relies on the specific scenario. Indeed, the selection is highly influenced by (i) the maximum extra overhead devoted



(a) Row-wise

(b) Column-wise

Fig. 1. Generation of repair packets with standard Pro-MPEG COP3 codes. Example with $D = 4$ and $L = 5$

to protection purposes, b_{FEC}, and (ii) the maximum tolerable latency, which jointly with the packet transmission arrangement, and the video bitrate determine the maximum value of k. The actual configuration is selected considering the behavior of the communication channel.

Pro-MPEG COP3 codes are characterized by its extremely low complexity in terms of the repair packet generation scheme and the operations involved. Unlike other state-of-the-art codes, like Raptor or RaptorQ codes [9], redundancy is generated through the straightforward one-step process described above, which very much eases their implementation and deployment.

3. PROPOSED EXTENSION TO THE PRO-MPEG COP3 CODES

Our proposal takes as a starting point the k video packets within the protection block, jointly with a set of k values that express their unequal importance, in terms of the potential distortion that their loss might introduce in the decoded sequence. These values are the result of applying a distortion model to the packet stream. The actual distortion model is out of the scope of this paper. However, an extensive selection of proposals can be found in the literature, like the ones in [10], [11] or [12].

The new extension allows the arrangement of the k packets in a set of m matrices of dimensions $\{D_i, L_i\}, 1 \leq i \leq m$, so that all packets are used and each one is included in just one matrix. The number of data packets that can be arranged in each matrix is $k_i = D_i \cdot L_i, 1 \leq i \leq m$. Additionally, the parameter b_{FEC} is considered for limiting the overall number of repair packets that can be generated per block, and so:

$$\sum_{i=1}^{m}(D_i + L_i) \leq b_{\text{FEC}} \cdot k$$

The mapping between packets and matrices is done in the following fashion: the k_1 most relevant packets, according to the distortion model, are arranged in the first matrix, the following k_2 are arranged in the second one, and so on.

The selection of the number of matrices to use and their configuration relies on the unequal importance of the packets in the stream, considering the adopted distortion model, and on the channel's behavior. In this paper, we present an exhaustive analysis of the novel extension. Hence, the most suitable selection has been chosen after considering all the possible options. However, optimized search techniques might be employed in some scenarios to fulfill latency requirements.

Finally, since the most convenient packets to be protected together may not lay sequentially in the bitstream, we allow the layout of non-consecutive packets in the matrices. For that reason, the signaling of the data packets XORed to create the repair packets varies with respect to the standard case. In the latter, only the inclusion of the matrix dimensions is needed, as expressed in RFC 6015 [13]. However, if our proposal is used, data packets need to be explicitly signaled, either employing a mask or a similar mechanism. That might involve an increase in bandwidth occupation, as a header extension may be needed to identify all the data packets in the FEC block. However, this extra bandwidth will not imply a significant rise, as long as the fixed network Maximum Transmission Unit (MTU) is not exceeded. We estimate that, if a simple signaling scheme is used, similar to the one in RFC 5109 [14], approximately $\lceil k/8 \rceil$ extra octets will be required per parity packet, which is a rather limited amount, compared to usual repair packet sizes (slightly longer than data packets). Moreover, the general framework defined in the more recent RFC 6363 [15] allows more flexible FEC packet field layouts, which might lead to more compact signaling schemes.

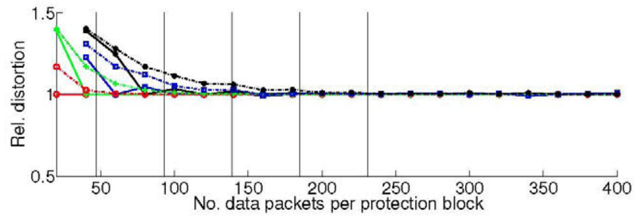
4. EVALUATION OF THE PROPOSED EXTENSION ADAPTED TO THE CONSIDERED SCENARIO

In this section, we present the experiments and the subsequent analysis through which we discuss the benefits of our proposal. The evaluation consists in a direct comparison between the performance of the proposed extension when employing different number of matrices, and that of the standard codes, under a wide range of conditions.

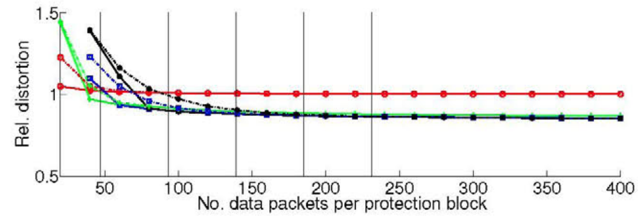
The evaluation has been carried out considering a specific scenario, in which it is assumed that the faced communication channel is essentially bursty (e.g. DSL and wireless networks). Under this supposition, we only consider parity packets generated column-wise. This restriction also deeply simplifies the process of selecting the best configuration.

Additionally, for the simulations, we emulate the values associated to the different packets, that is, those delivered by the distortion model. To that end, we assume that these values can be approximated employing certain functions.

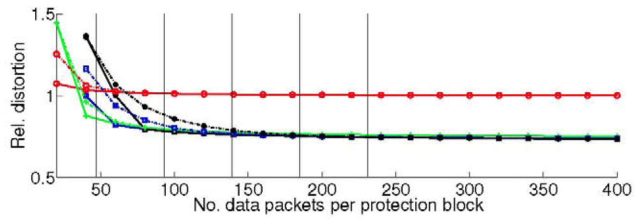
To evaluate our proposal, we have considered a great number of contexts, regarding the variety of parameters involved and their values: the number of matrices used, m, the video bitrate, R_{video}, the protection bandwidth overhead, b_{FEC}, the number of data packets per FEC block, k, the function expressing the relative distortion value of the data packets, d_k, the model reflecting the behavior of the channel, C, and the PLR, p_e. The values used in the tests are detailed in Table 1.



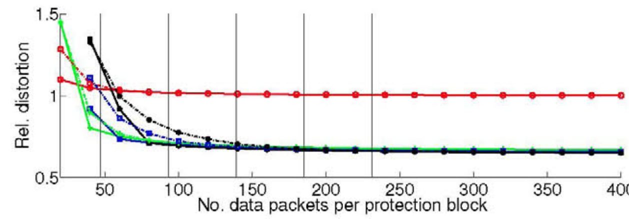
(a) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-1}$, d_{k} uniform



(b) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 20$ %, $p_{\text{e}} = 10^{-1}$, d_{k} linear



(c) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-1}$, d_{k} quadratic



(d) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 20$ %, $p_{\text{e}} = 10^{-1}$, d_{k} cubic

Fig. 2. Resulting distortion derived from using 1 to 4 matrices to protect the number of data packets indicated in the horizontal axis, subject to the same scenario conditions ($R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-1}$), but assuming the different distortion function indicated for each graph. The use of dissimilar number of matrices is plotted in different colors and with dissimilar markers: one matrix in red with circles, two matrices in green with crosses, three in blue with squares, and four in black with stars. In addition, solid lines represent the REIN model, whereas dashed lines are used for the simplified G-E model

Table 1. Test parameters

Parameter	Values
m	1 to 4
R_{video}	2.5 Mbps, 5 Mbps
b_{FEC}	10 %, 20 %
k	20 to 400
d_k	Uniform, linear, quadratic, cubic
C	REIN, simplified G-E
p_{e}	10^{-2}, 10^{-1}

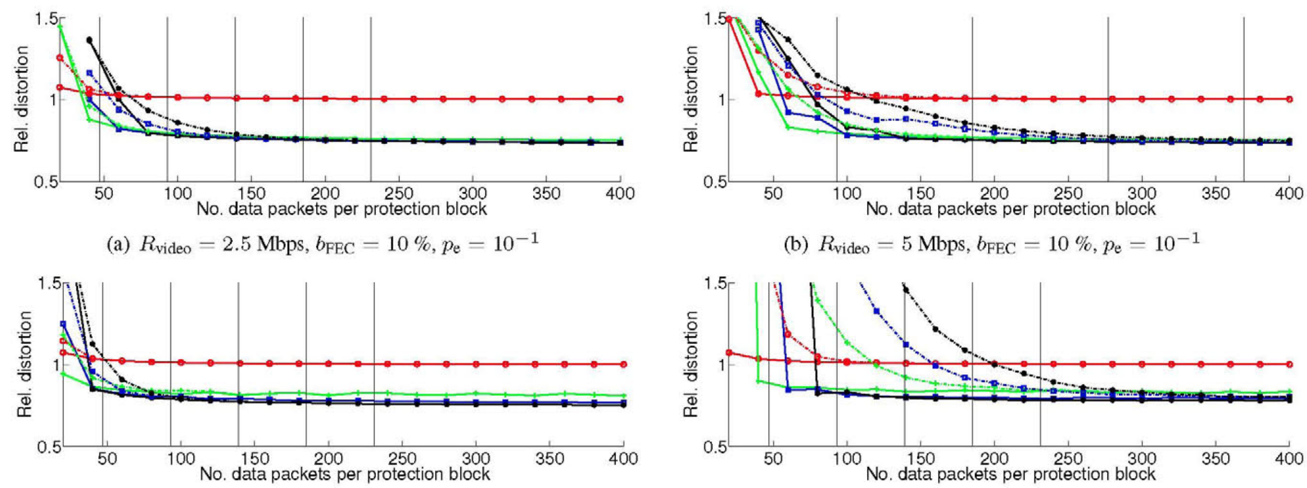
Results are given, for each configuration and context, in terms of the overall expected distortion, which equals the summation of the expected distortion of all the packets in the protection block. This value is computed as the distortion value given by the distortion model, multiplied by the likelihood of losing that packet during transmission and not being able to recover it. Moreover, for a more suitable analysis of results, overall distortion values have been normalized with respect to a reference value. This value equals the best result obtained using the standard mechanism under the same conditions, allowing the bigger protection block considered in the simulations, 400 video packets. So, it becomes much easier to discern, based on the range between the different configurations, the benefit or damage derived from their use.

Figure 2 shows the results of the experiments for a specific context ($R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, and $p_{\text{e}} = 10^{-1}$). The different graphs have been generated using dissimilar functions to obtain the packet distortion values. The horizontal axis expresses the number of packets available in the FEC block. The depicted relative distortion value is, for each value of k, the one obtained with the most convenient combination of matrix sizes, given the maximum allowed number of repair packets (computed as $k \cdot b_{\text{FEC}}$). As a reference, black vertical lines have been added to mark different latency periods, concerning the time devoted to wait for data packets before applying the protection algorithm: 200, 400, 600, 800 and 1000 ms. So, one can check the number of data packet available in each case after this waiting.

In light of these data, we can claim that the results obtained when using the proposed extension outperform the ones with the standard case, provided that the protection scheme has enough capability to simultaneously (i) cope with burst errors, and (ii) provide unequal protection to video packets, regarding their importance. Having enough capability ultimately means having enough number of repair packets to be able to generate suitable configurations to those ends. This power completely depends on the specific context.

So, if the context allows the generation of enough number of repair packets, we observe that the overall distortion decreases with the number of matrices used, as long as the data packets are not uniformly relevant. In fact, the more unequal the video packets are, considering the distortion value associated, the greater the gain obtained when increasing the number of matrices. Additionally, the gain resulting from increasing the number of matrices per FEC block, i.e., using $m + 1$ matrices instead of m, gets smaller with m.

Regarding the type of communication channel, we can see that, in the case of encountering a channel in which bursts are of a fixed length, as the one modeled with the REIN model, rather small FEC blocks suffice to be able to generate enough parity packets so as to be able to cope with bursts and provide adaptive protection. The reason is that a smaller number of columns is needed to ensure error decorrelation (equal



(a) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-1}$

(b) $R_{\text{video}} = 5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-1}$

(c) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 20$ %, $p_{\text{e}} = 10^{-1}$

(d) $R_{\text{video}} = 2.5$ Mbps, $b_{\text{FEC}} = 10$ %, $p_{\text{e}} = 10^{-2}$

Fig. 3. Resulting distortion derived from using 1 to 4 matrices to protect the number of data packets indicated in the horizontal axis, subject to different scenario conditions, except for the function approximating distortion values, which is the same for all the graphs. The use of dissimilar number of matrices is plotted in different colors and with dissimilar markers: one matrix in red with circles, two matrices in green with crosses, three in blue with squares, and four in black with stars. Finally, solid lines represent the REIN model, whereas dashed lines are used for the simplified G-E model

or greater than the number of packets affected by a single burst). This can be spotted in the presented graphs, where systems using the proposed extension and facing those channels quickly outperform the standard technique.

In channels where losses take place in bursts of variable length, as the one modeled with the simplified Gilbert-Eliot (G-E) model, a greater k is necessary to outperform the standard mechanism, as more columns per matrix are needed to reach error decorrelation.

The above mentioned graphs show a general tendency for the whole set of simulations. Indeed, altering the scenario conditions basically affects (i) the range between the different configurations, and (ii) the influence of the size of the protection block. A second figure, Fig.3, has then been included with the aim of illustrating the specific effect of the rest of the parameters analyzed: R_{video}, b_{FEC}, and p_{e}. It contains four graphs where d_{k} is always quadratic. The first one, Fig.3(a), is just a reposition of the corresponding graph in Fig.2. The rest of them present the results obtained after modifying the value of the indicated parameter with respect to the first one.

In Fig.3(b), we can observe that, if the video bitrate is higher, systems implementing the proposed extension require a greater FEC block to outperform the standard codes and converge to a steady performance. The reason is the following: more data packets are lost within a single burst, and thus, more parity packets are needed to effectively decorrelate channel error. This is not a problem in terms of time, as the number of packets received in the same period rises in the same proportion of the bitrate. However, it increases the complexity of the process to obtain the optimum configuration. In the case of very high bitrates, optimized search techniques might be required to fulfill latency restrictions.

On the contrary, Fig.3(c) illustrates that greater protection bandwidth overheads allow the system employing the extension to use smaller FEC blocks to be able to outperform the standard case.

In addition, Fig.3(d) shows that, as p_e increases, the system requires fewer repair packets to outperform the standard technique. This conclusion is of special interest to us, as the main motivation of our work is to improve the performance of the Pro-MPEG COP3 codes for high PLRs, where these codes are weaker.

5. CONCLUSIONS

In this paper, the broadly-known and used AL-FEC Pro-MPEG COP3 codes are extended to enable the unequal error protection of bitstreams, so as to improve their performance, especially at high channel PLRs, where the standard codes are weaker. Our proposal lies in allowing the use of a number of matrices of unequal dimensions to protect the data packets in the FEC block. This enhancement allows a better adaptation to the video stream, as different FEC code rates can be applied to dissimilar groups of data packets, regarding their relevance in terms of error propagation.

Additionally, we have carried out an exhaustive evaluation of the proposed extension, comparing its performance with the one of the standard mechanism, for a wide range of possible scenarios, regarding the parameters analyzed and their values. Evaluation results show a notable gain of our proposal over the standard case, as long as the protection scheme has enough capability to simultaneously deal with burst errors and provide unequal protection to data packets.

6. REFERENCES

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